Long-distance Dating: In situ geochronology for planetary missions

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KArE

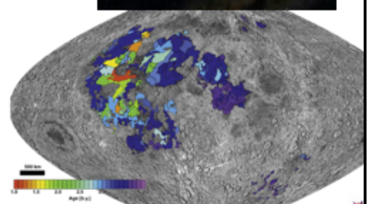
Geochronology: More than just rock ages

- What are the constraints on the **time evolution** of the dynamic solar system?
  When did the outer planets migrate and the asteroid belt lose mass?
  How did it affect other bodies **at that time**?

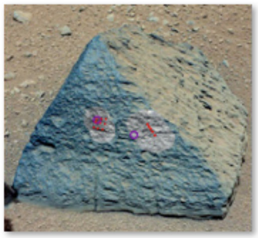
- **When** was Mars warm and wet?
  How much time did organisms have to thrive in this environment?
  What was going on elsewhere in the solar system **at this time**?

- **How long** were planetary heat engines active?
  What are the differences in heat dissipation and magma formation between the Moon, Mars, and large asteroids?

- **How long** have current surfaces been exposed to (and possibly changed by) the space environment?



Materials suitable for K–Ar dating

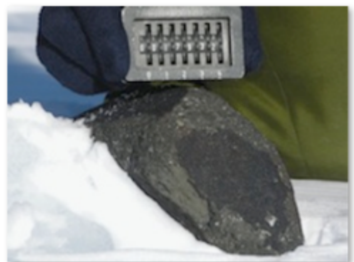


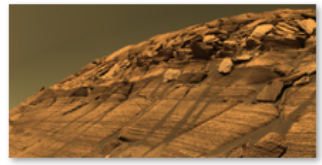
Igneous rocks

- K-rich accessory minerals to give wide spread of parent/daughter
- Well-studied ^{40}Ar-^{39}Ar ages and diffusion characteristics (based on meteorites)

Phyllosilicates (clays)

- Identified on Mars and asteroids
- Indicator of neutral, habitable environment
- May hold biosignatures
- K-rich illite common in basalt-derived phyllosilicate assemblages





Sulfates

- Widespread on Mars
- Indicator of acidic, generally uninhabitable environment
- K-rich jarosite common in terrestrial sulfate assemblages
- Well-studied ^{40}Ar-^{39}Ar ages and diffusion characteristics

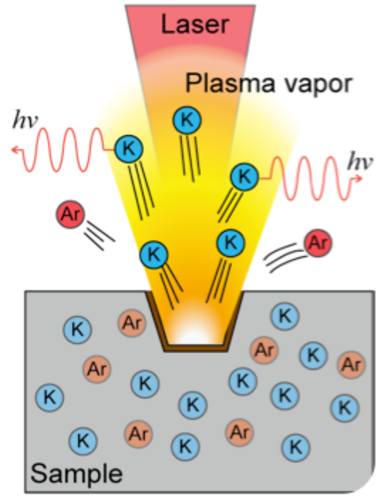
KArLE (K–Ar Laser Experiment) concept

- K–Ar age of rocks

$$t = \frac{1}{\lambda} \ln\left(\frac{\lambda}{\lambda_e} \frac{[^{40}\mathrm{Ar}]_{\mathrm{rad}}}{[^{40}\mathrm{K}]} + 1\right)$$

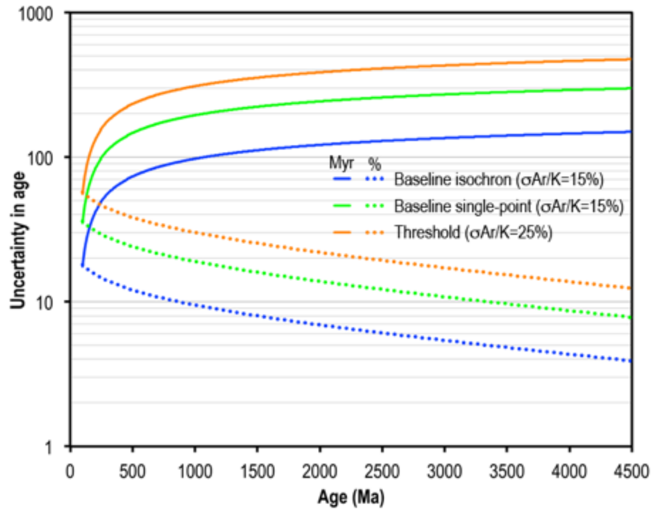
  1. K measured using laser-induced breakdown spectroscopy (e.g. ChemCam), also ablates the rock
  2. Liberated Ar measured using mass spectrometry (e.g. SAM)
  3. K and Ar related by volume of the ablated pit using optical measurement (e.g. MAHLI)

- Use TRL 9 components to achieve new science
  - payload synergy
  - reasonable cost
  - low risk
  - near-term implementation



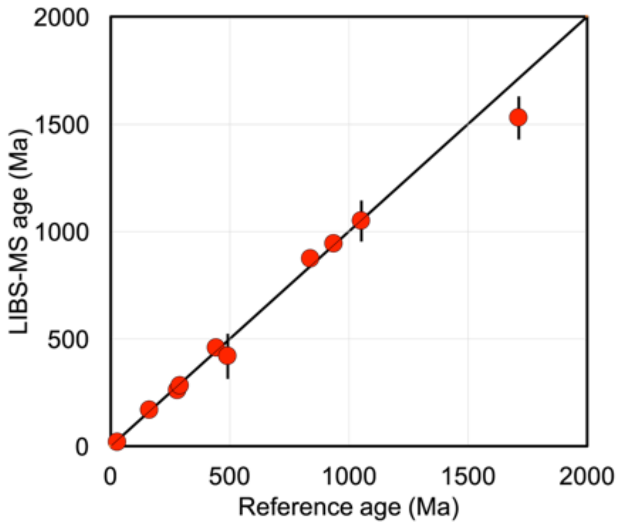
Precision and Range

- K-Ar ages increase logarithmically with the Ar/K ratio
- Uncertainty in age increases as a quadratic combination of the relative errors ($\sigma_{Ar/K}$)
- For fixed measurement uncertainties, the uncertainty in age becomes a smaller fraction of the age (more precise) as ages increase - a feature for planetary samples



K Ar E

LIBS-MS Measurements



Results from multiple laboratories yield whole-rock ages within error of accepted ages and precision close to theoretical
= TRL 4
(validation in the laboratory)

Solé (2014) Chemical Geology 388, p. 9-22; Cohen et al. (2014) Geostandards and Geoanalytical Research, doi: 10.1111/j.1751-908X.2014.00319.x; Devismes et al. (2016) Geostandards and Geoanalytical Research, doi: 10.1111/ggr.12118; Cho et al. (2016) Planetary and Space Science 128, 14-29

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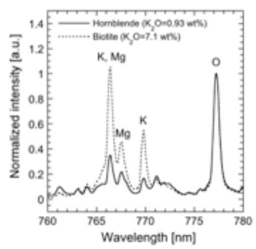
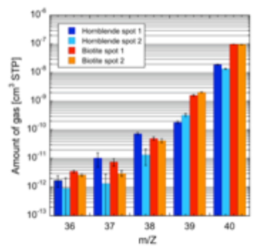
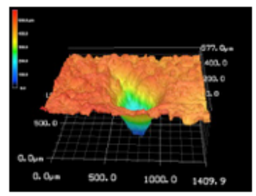
LIBS-MS Uncertainties

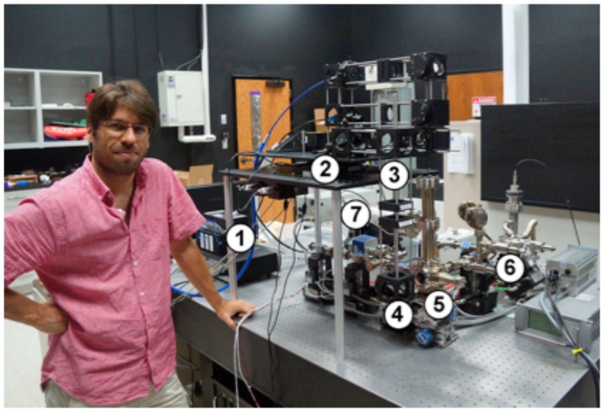
- LIBS measures K (σ_L=10%), also breaks sample matrix and releases noble gases
- ^{40}Ar and noble gases measured by mass spectrometry (σ_A=3-5%)
- Density from bulk composition (σ_ρ=5%)
- Volume from optical reconstruction or other methods (σ_V=10-15%)
- Actual magnitude of uncertainties set by calibration, element abundances, blanks, and backgrounds



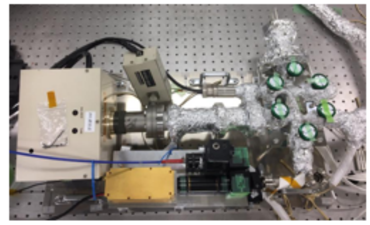




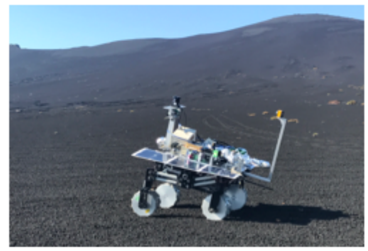
KArLE Breadboards



1- HR2500+ Ocean Optics spectrometer
2-Optical setup
3- Column for a camera recording the sideview of the plasma
4- Mirror
5- Ablation cell with sample handler coupled with a pre-chamber
6- Vacuum line including getter, pneumatic valves, turbomolecular pump
7- Mass Spectrometer (Hiden Analytics QMS / 1st Detect ITMS)



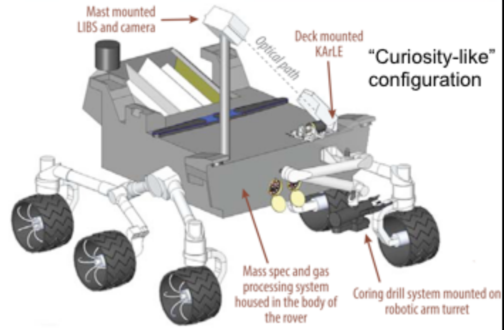
Breadboard ver.2 in Japan



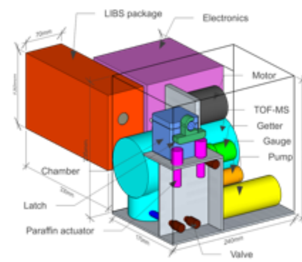
Field campaign (Nov. '16)

KArLE flight concept (examples)

- Partner-provided instrument suite; agnostic to specific analysis providers
- KArLE-specific hardware is mechanically simple
- Flexible implementation with multiple sample delivery systems
  – core, scoop, etc.
- Internal and external calibration targets monitor dust and vapor buildup
- LIBS+MS+camera payload ~15 kg; distributed volume; power = 10 – 66 W
- Chamber+sample handling ~variable but probably ~1-2 kg; low power (stepper motors, gasket preload)



“Curiosity-like” configuration



“Compact box” configuration

(Cho+ 2016)

KArLE

Summary

- *In situ* dating does not replace sample return
  — however, we can't get samples from everywhere in the solar system
- KArLE can determine the age of geologic samples with 10-15% precision, sufficient to address a wide range of fundamental questions in planetary science
- We achieve this using flight-proven components that enable thousands of measurements
- KArLE-specific hardware is a value-added addition to a synergistic payload that achieves analyses common to most planetary surface missions (elemental and volatile analysis, microimaging)
- Flight heritage of components ensures they will fit (mass, volume, power) on future landers or rovers to the Moon, Mars, Asteroids (Phobos, Vesta, Ganymede ….)